Multilayer mask roughness: the relative importance of phase and amplitude

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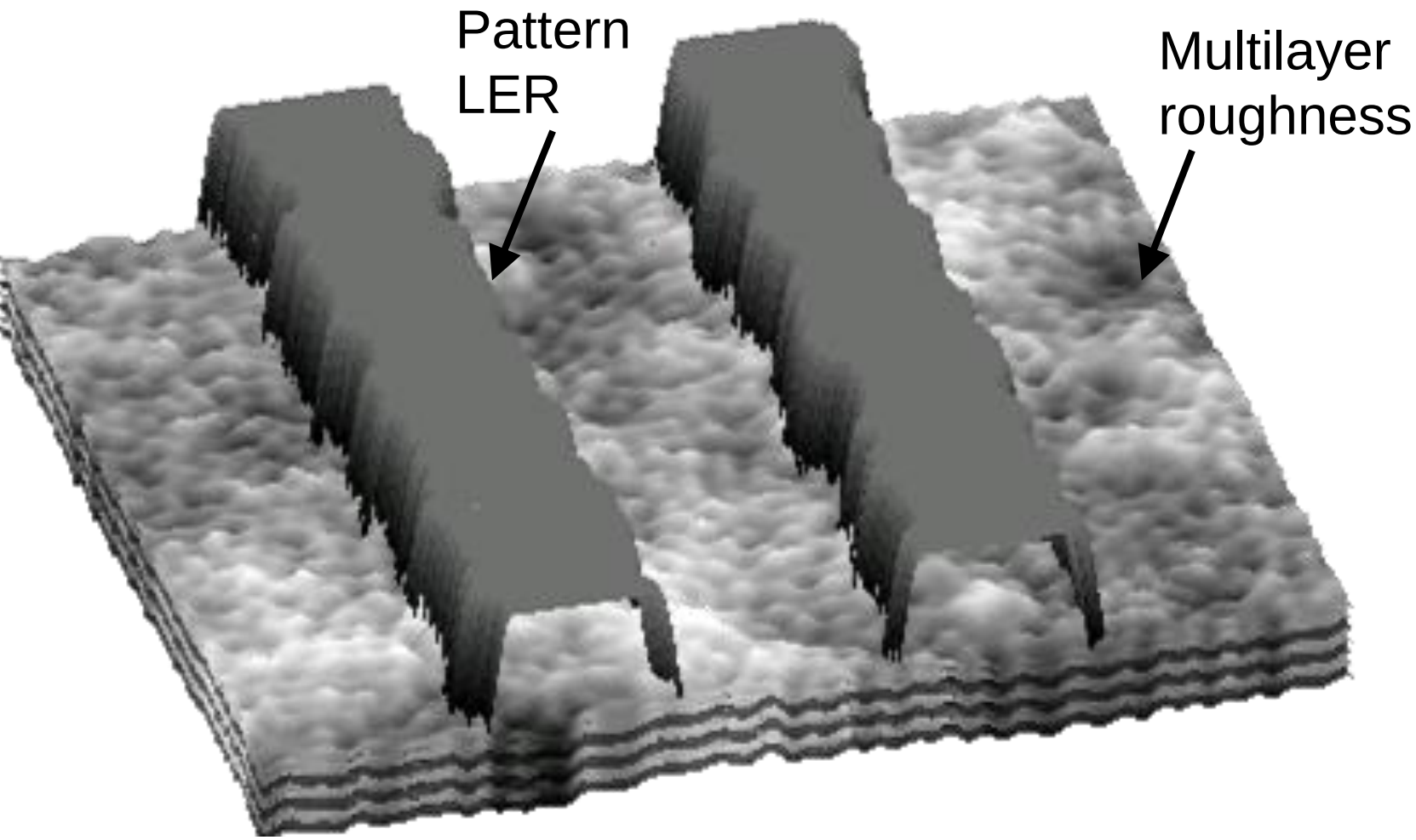




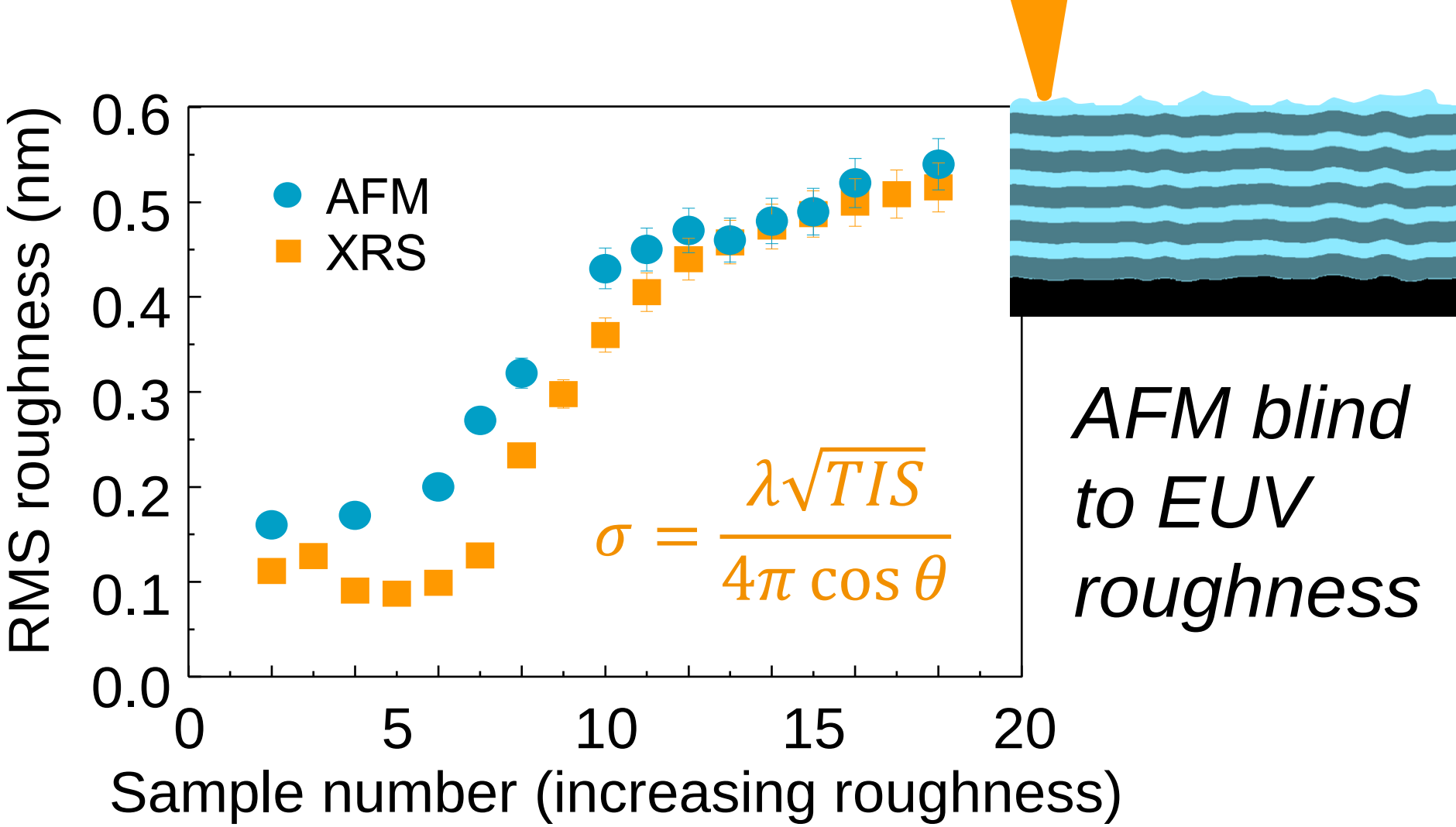


Outline

- Measuring multilayer roughness
- Phase/amplitude ambiguity
- Effect of amplitude roughness
- Experimental aerial imaging results

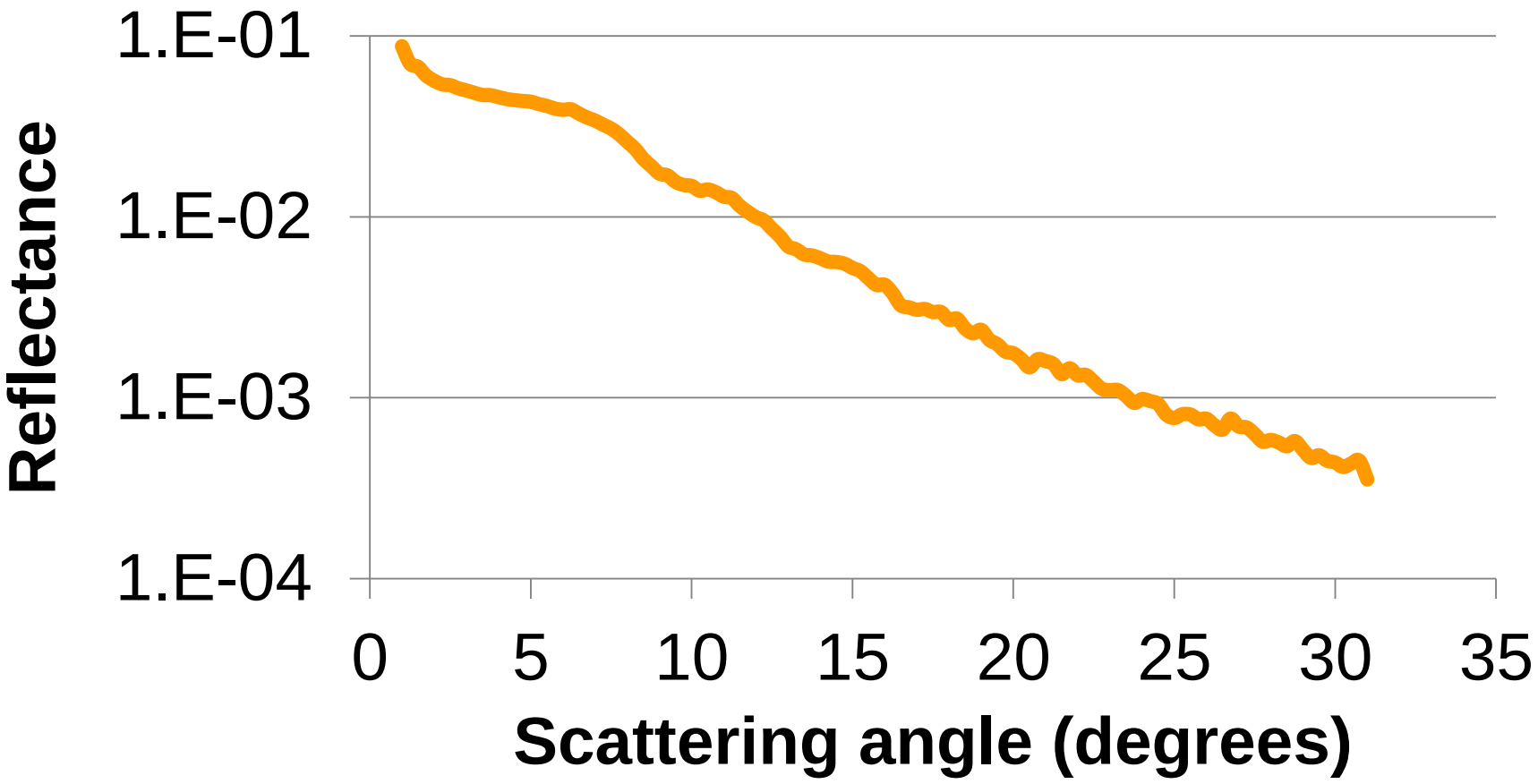


100-pm RMS roughness = 32° PV phase shift



AFM blind to EUV roughness

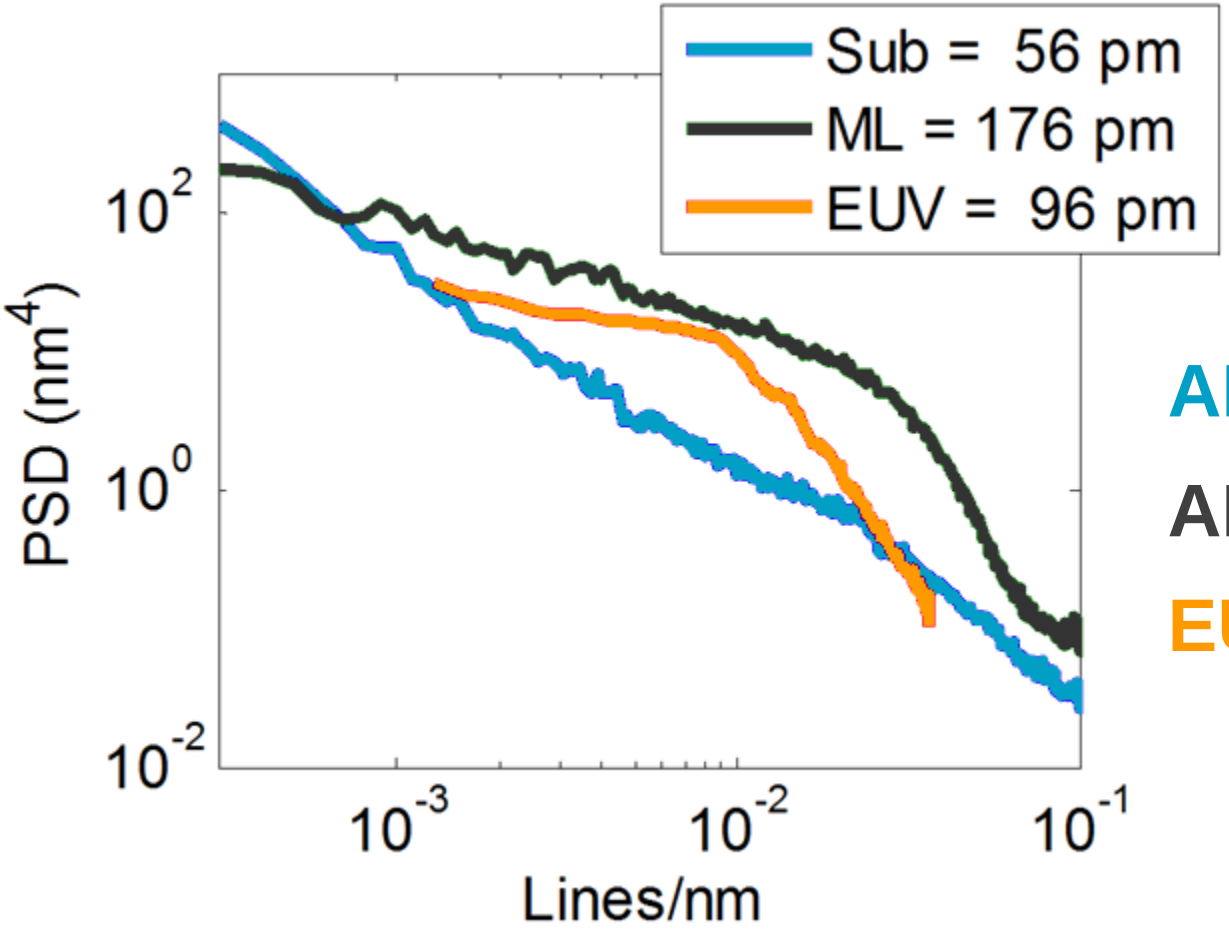
Compute surface PSD from scattering



Compute surface PSD from scattering

$$PSD(\theta_s) = \frac{R(\theta_s)\lambda^4}{16\pi^2 \cos(\theta_i)\cos^2(\theta_s)R_o}$$

The right metrology is key



AFM of substrate

AFM of ML

EUV scattering

Compute surface PSD from scattering

$$PSD(\theta_s) = \frac{R(\theta_s)\lambda^4}{16\pi^2 \cos(\theta_i)\cos^2(\theta_s)R_o}$$

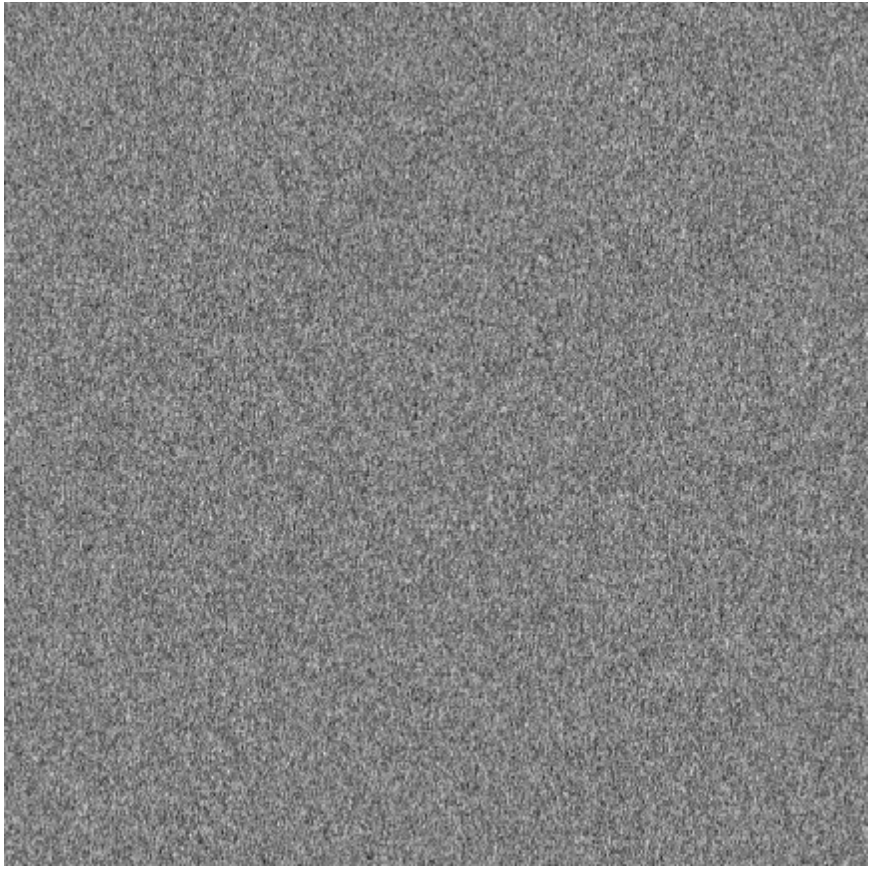
Rayleigh-Rice model assumes all scattering from small phase roughness

Problem: scattering cannot distinguish between amplitude and phase roughness

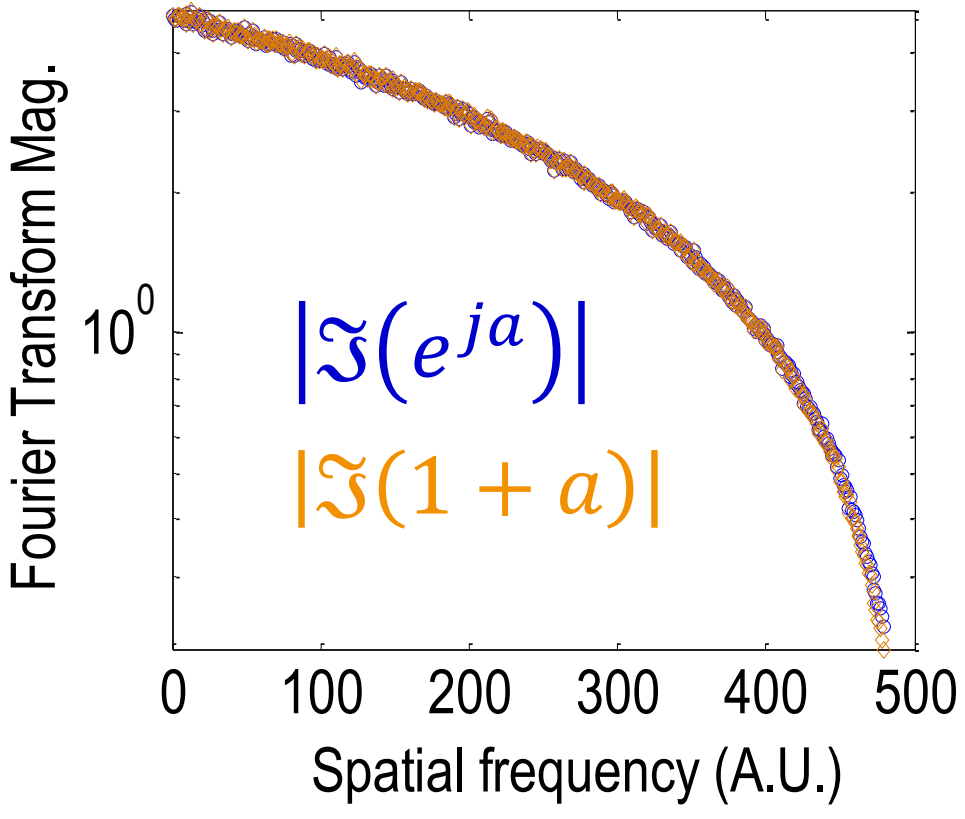
$$|\Im(1+a)| \sim \left|\Im\left(e^{ja}\right)\right|$$

Scattering identical

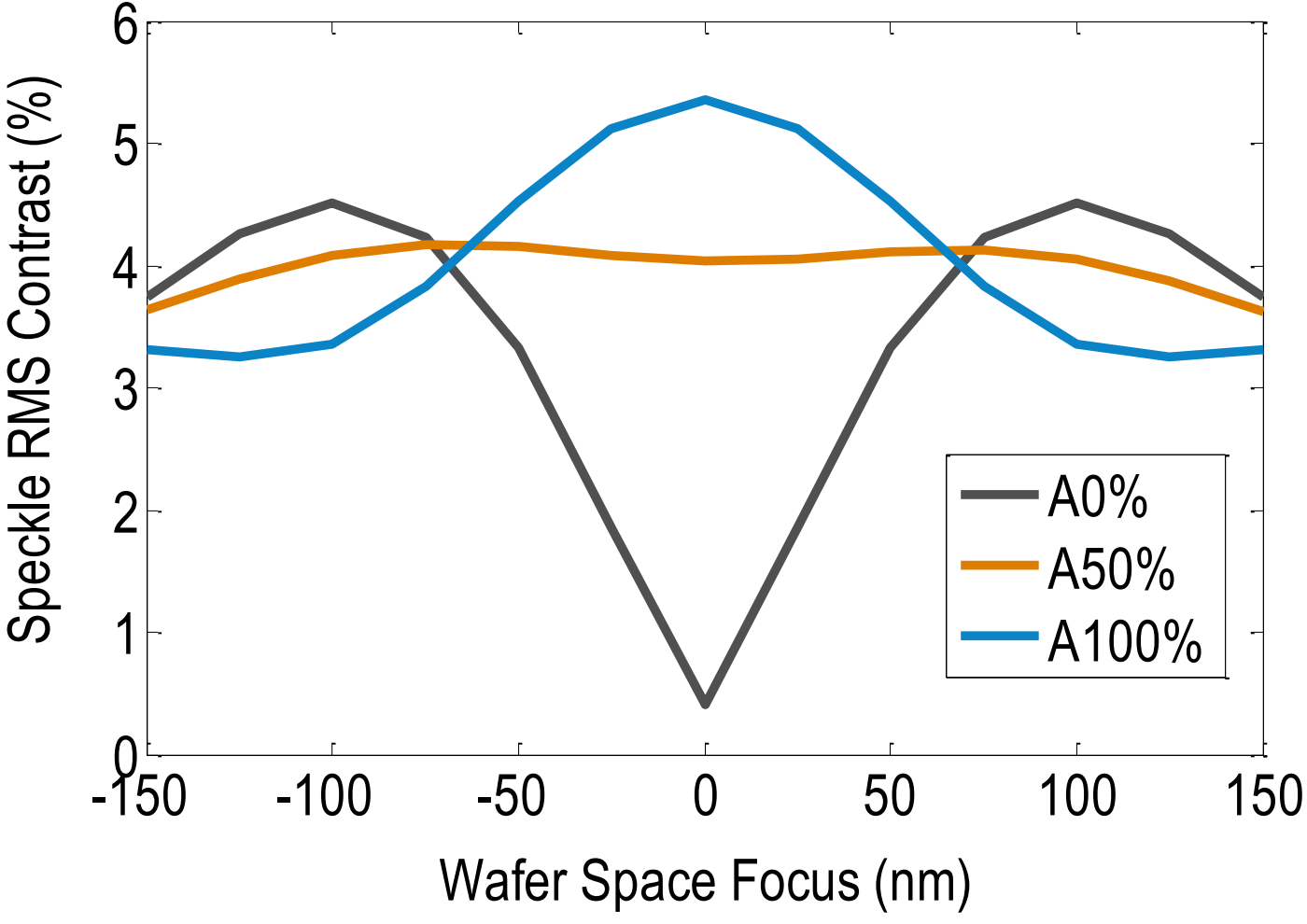
Image of a



$\sigma_a = 0.1$

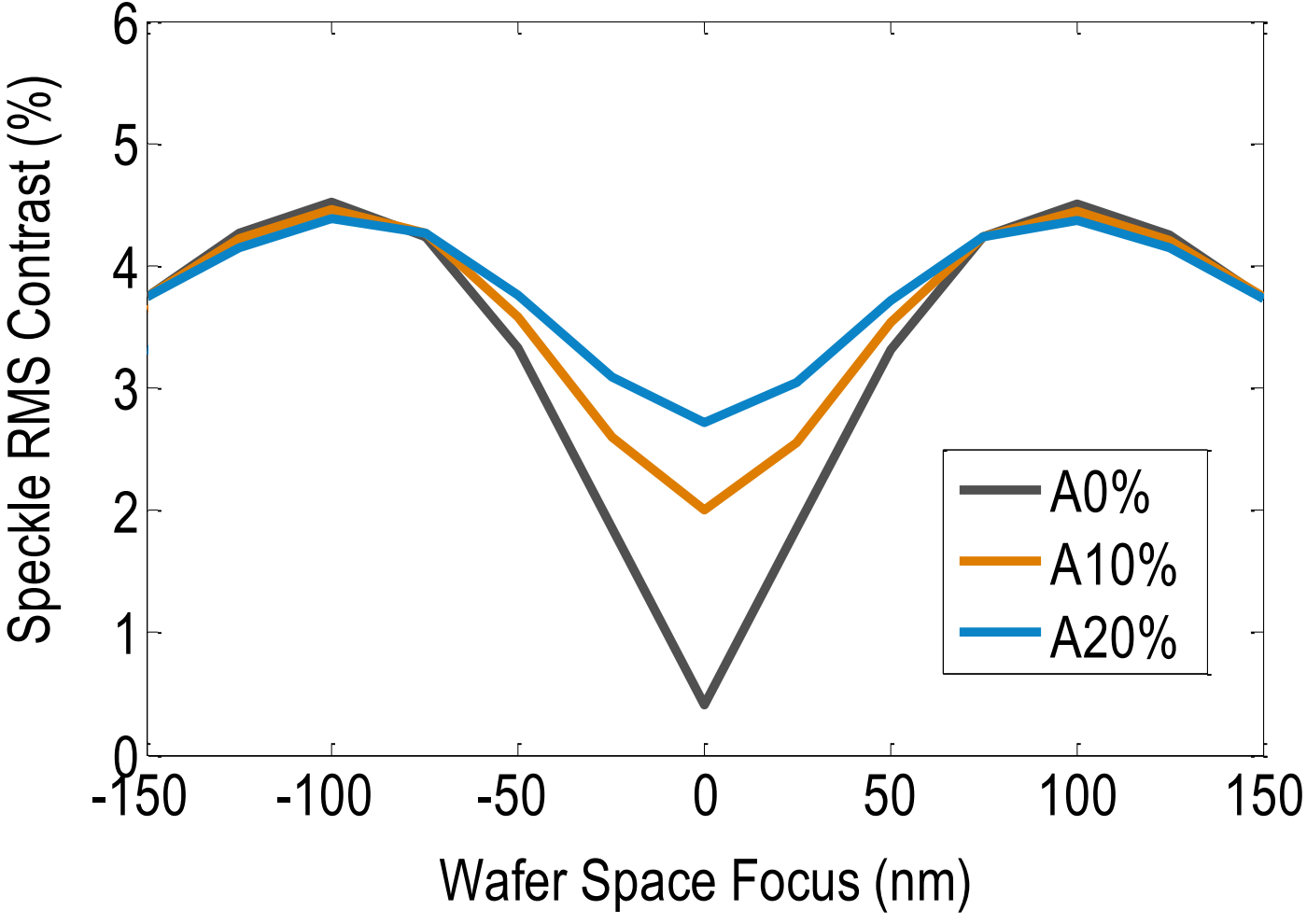


Yet, imaging impact very different



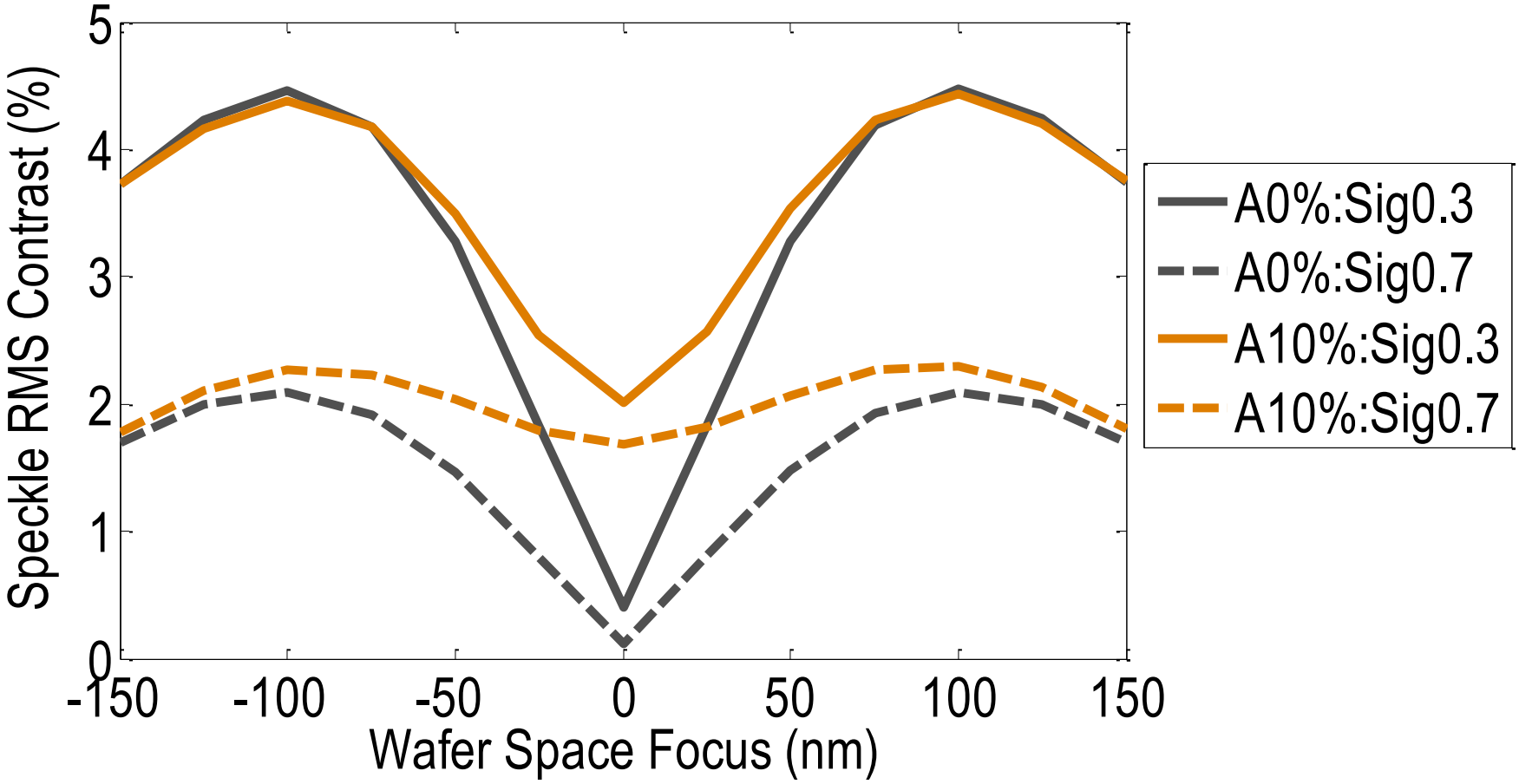
Partial coherence = 0.3

Yet, imaging impact very different

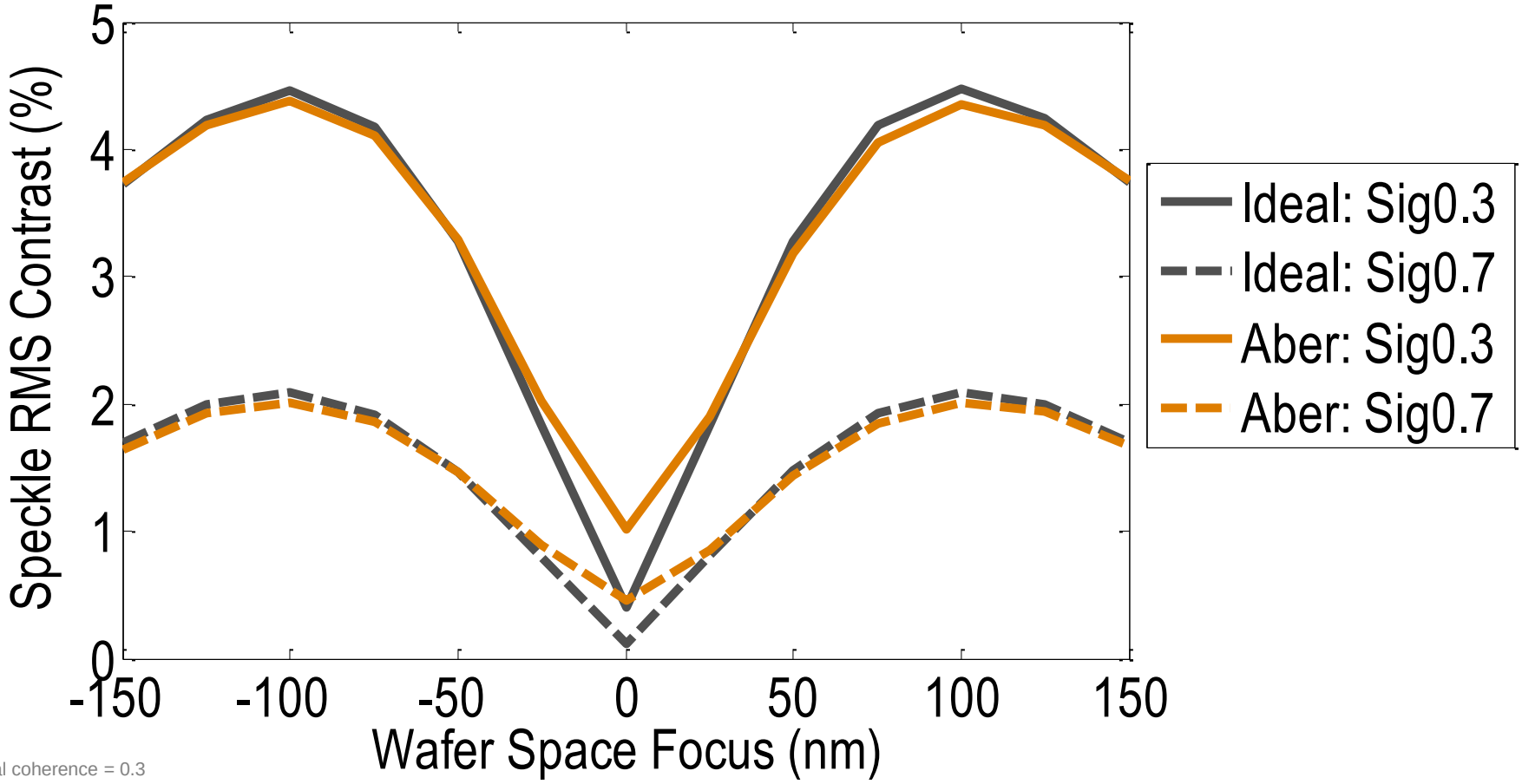


Partial coherence = 0.3

Amplitude ratio changes dependence on σ



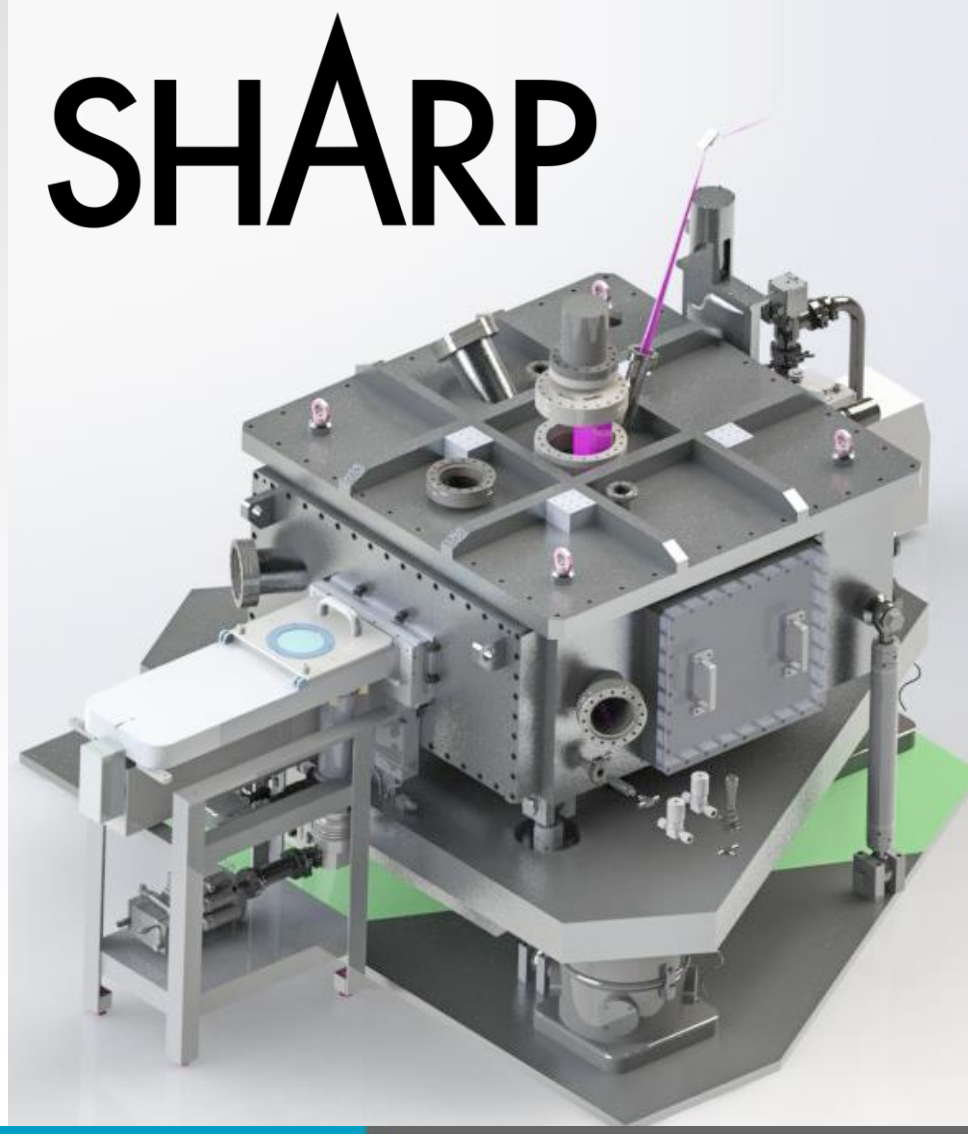
Aberrations show similar effect but smaller

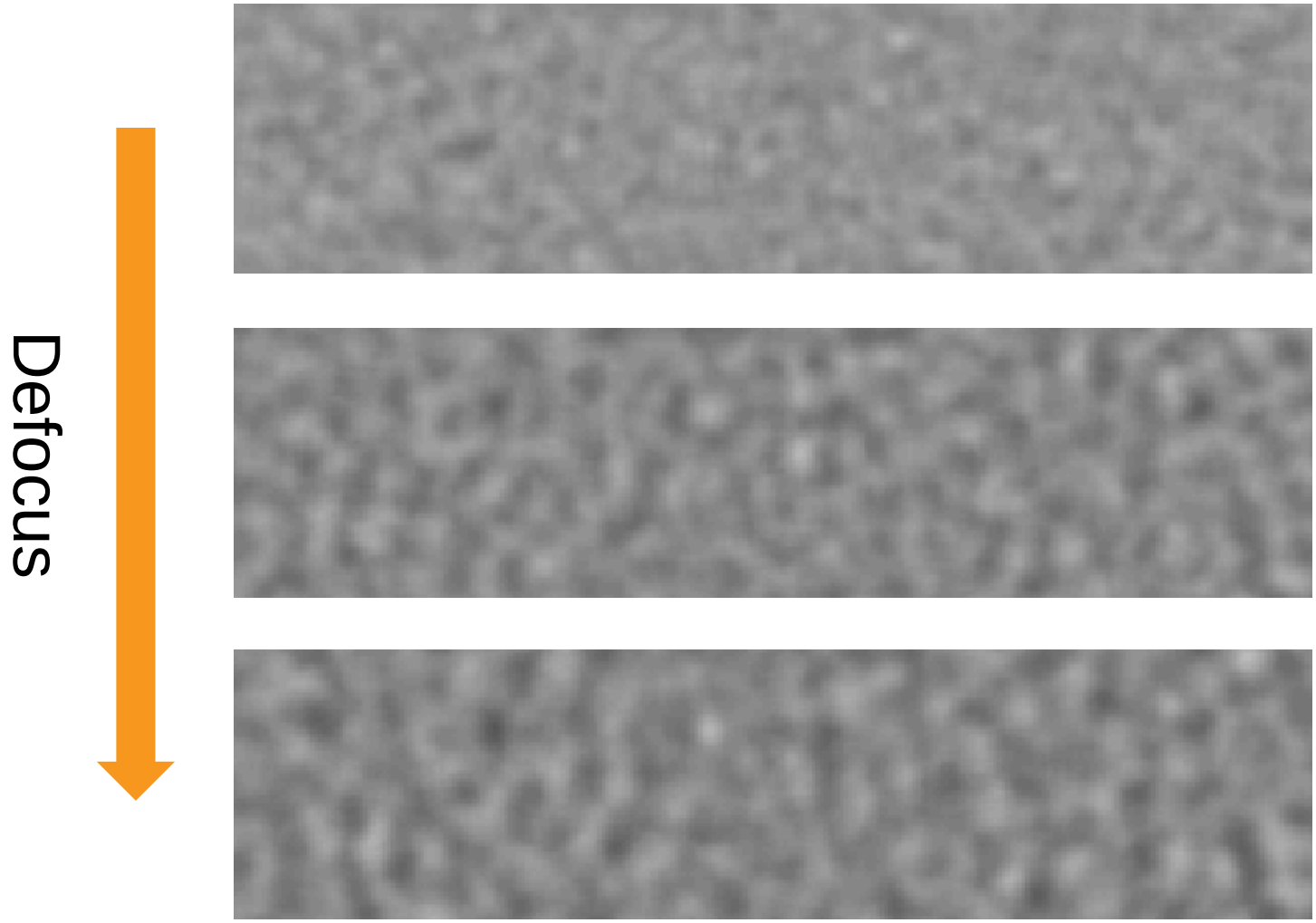


Partial coherence = 0.3
0.44-nm wavefront aberration

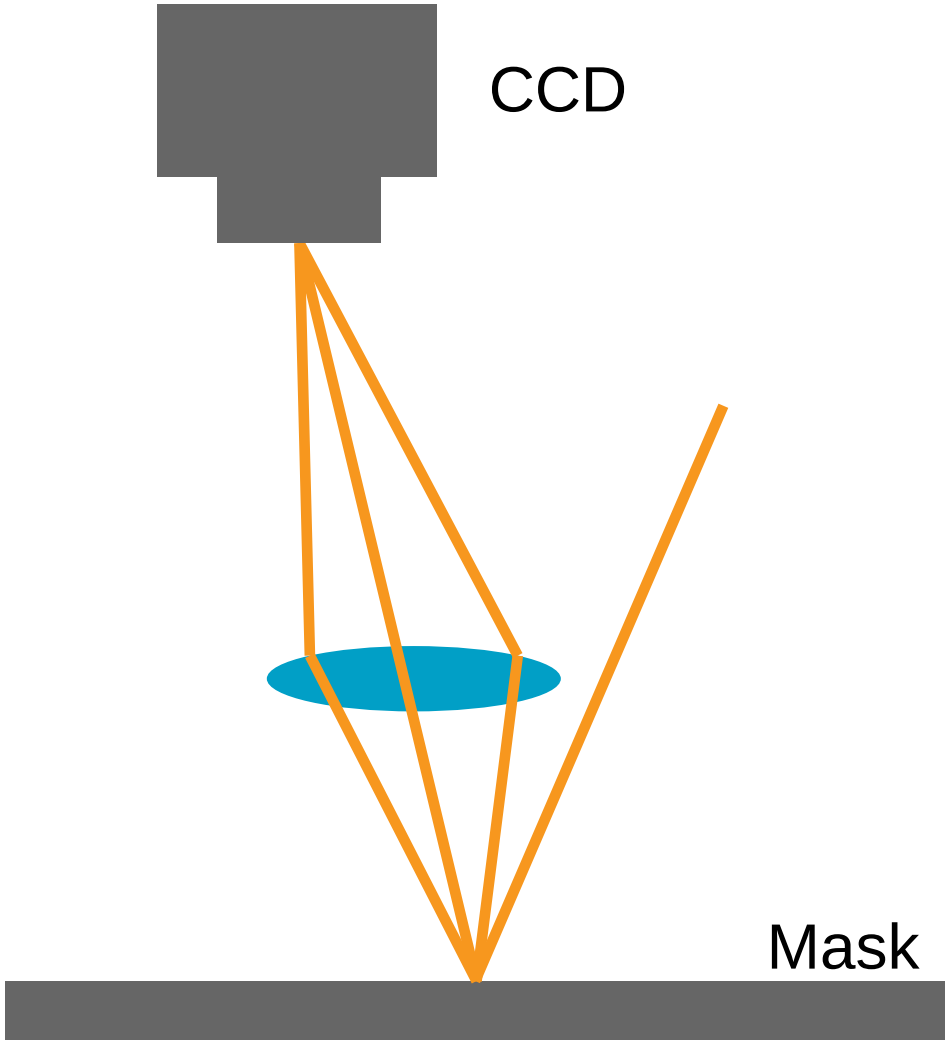
SHARP

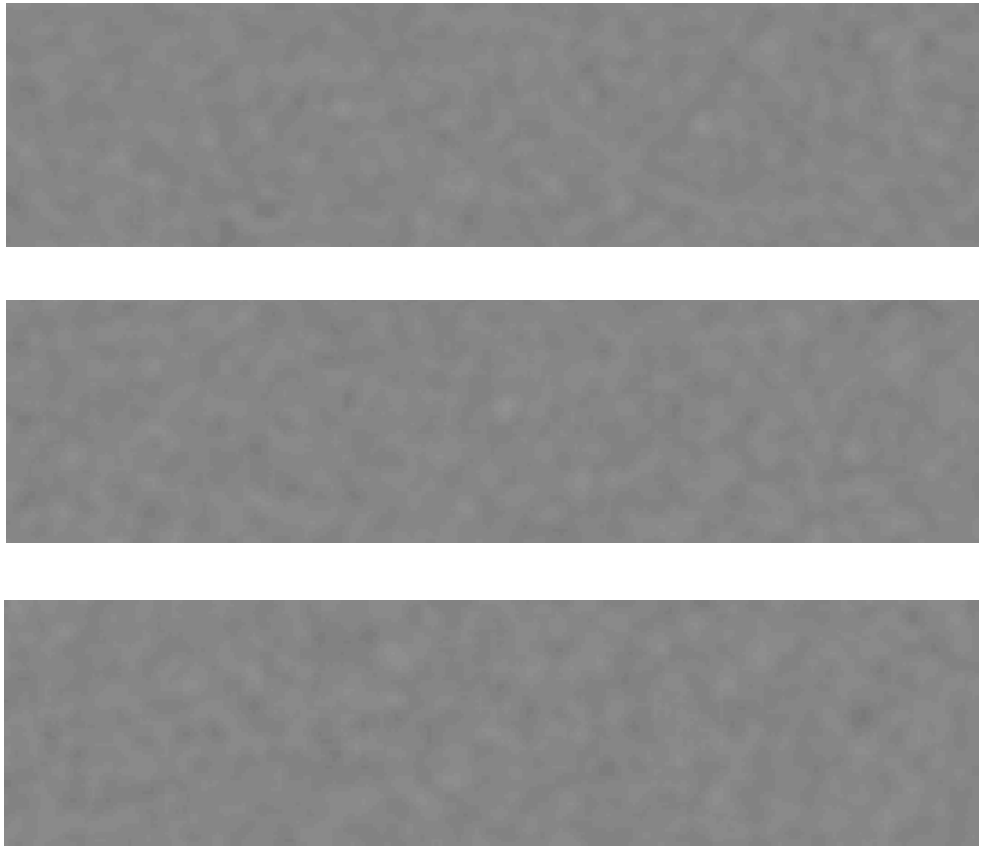
- **Source:**
 Synchrotron
- **Optics:**
 Zoneplate-lenses
- **Effective NA:**
 0.250–0.625
- **Coherence:**
 Programmable

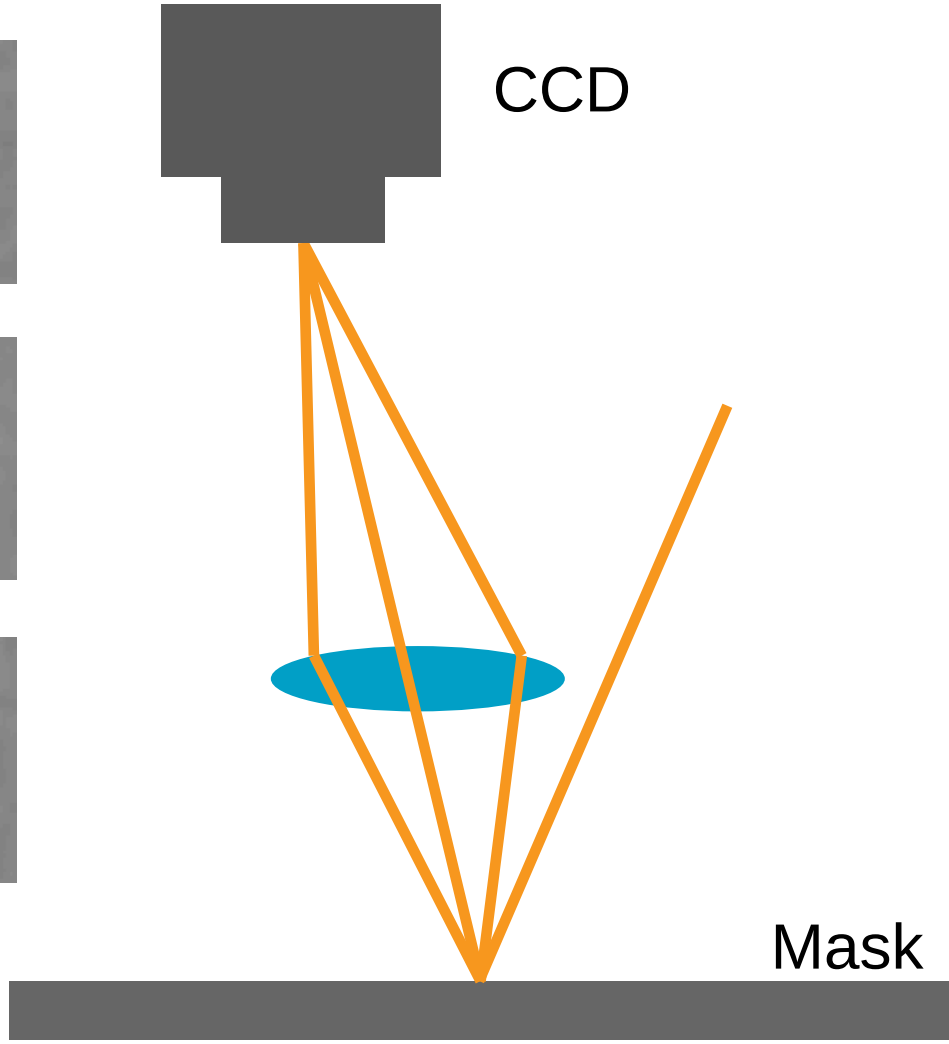



Defocus

Determine measurement contributions to speckle





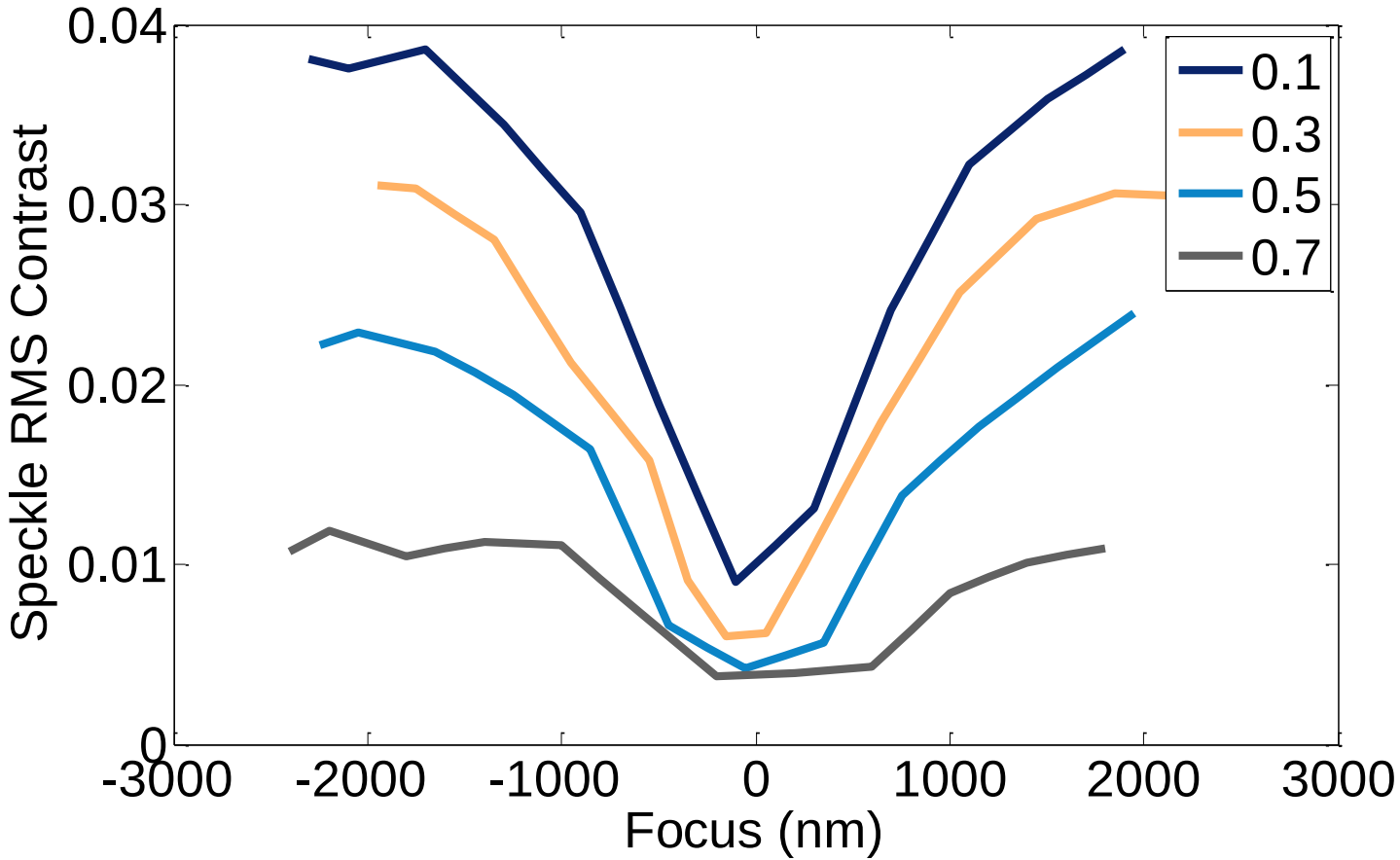


Measurement noise = 1.8%

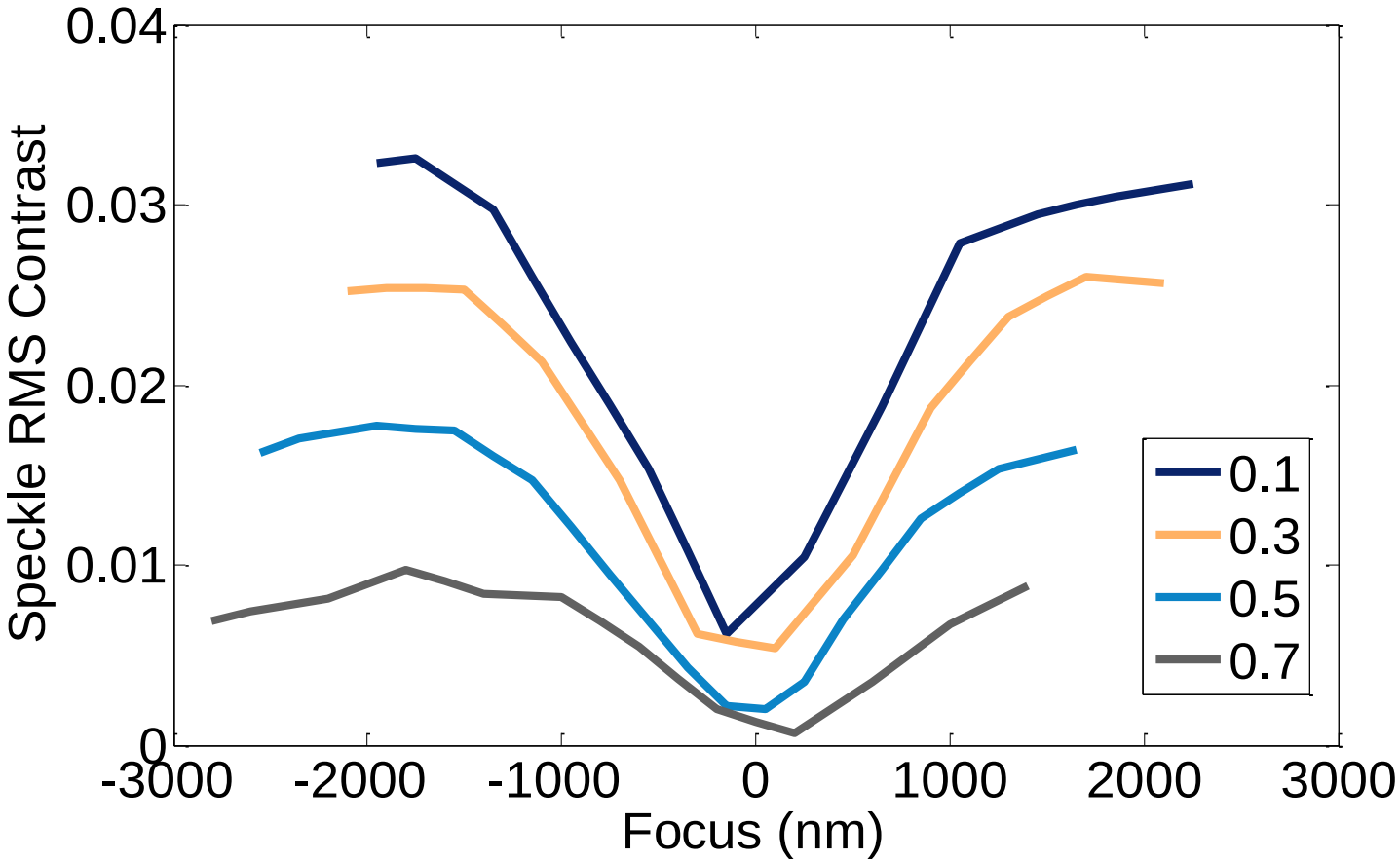
Measure through focus speckle for 3 masks with decreasing roughness

110 pm $\Rightarrow$ 61 pm

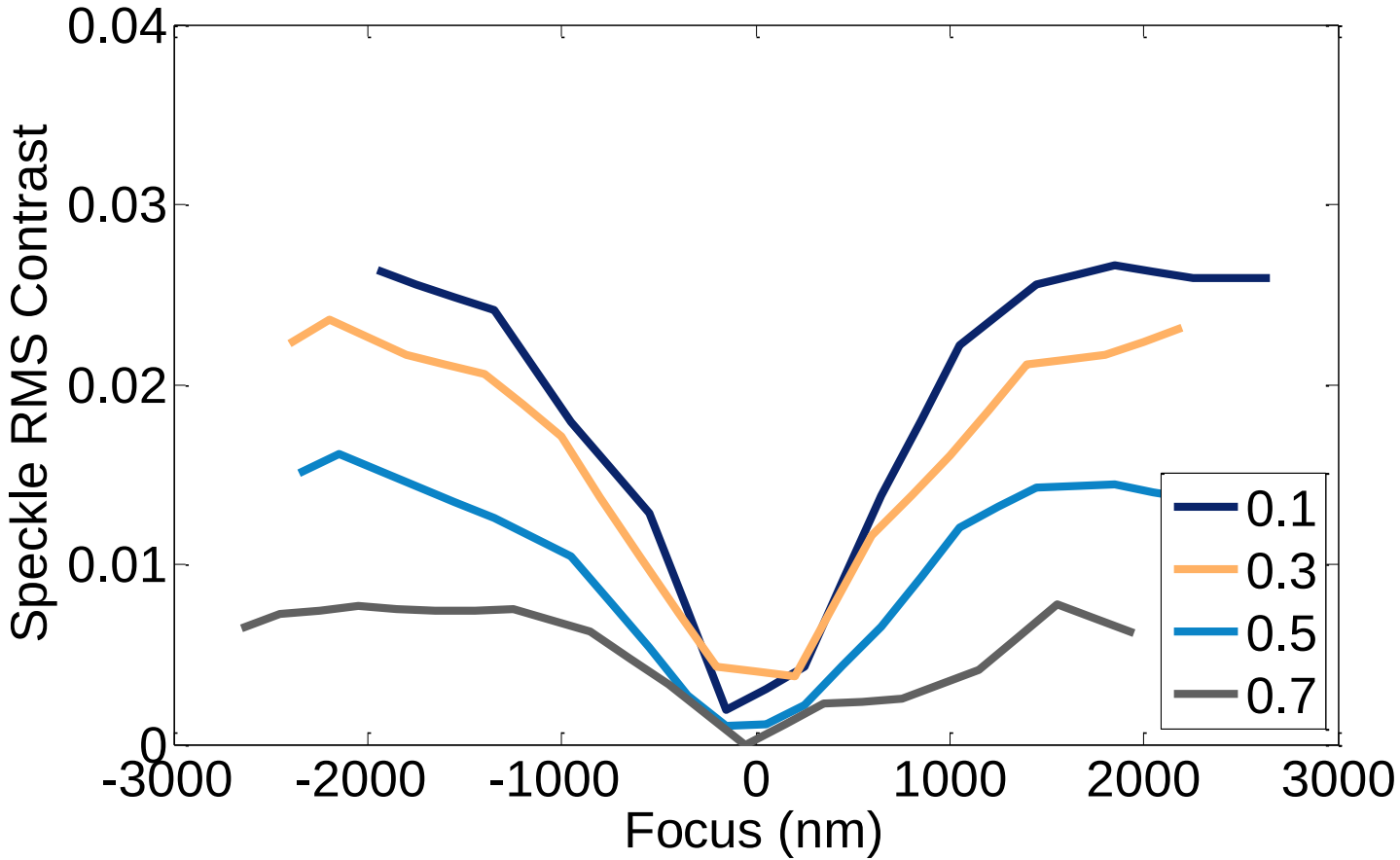
Mask 1


0.04
0.03
0.02
0.01
0
Speckle RMS Contrast
-3000
-2000
-1000
0
1000
2000
3000
Focus (nm)
0.1
0.3
0.5
0.7

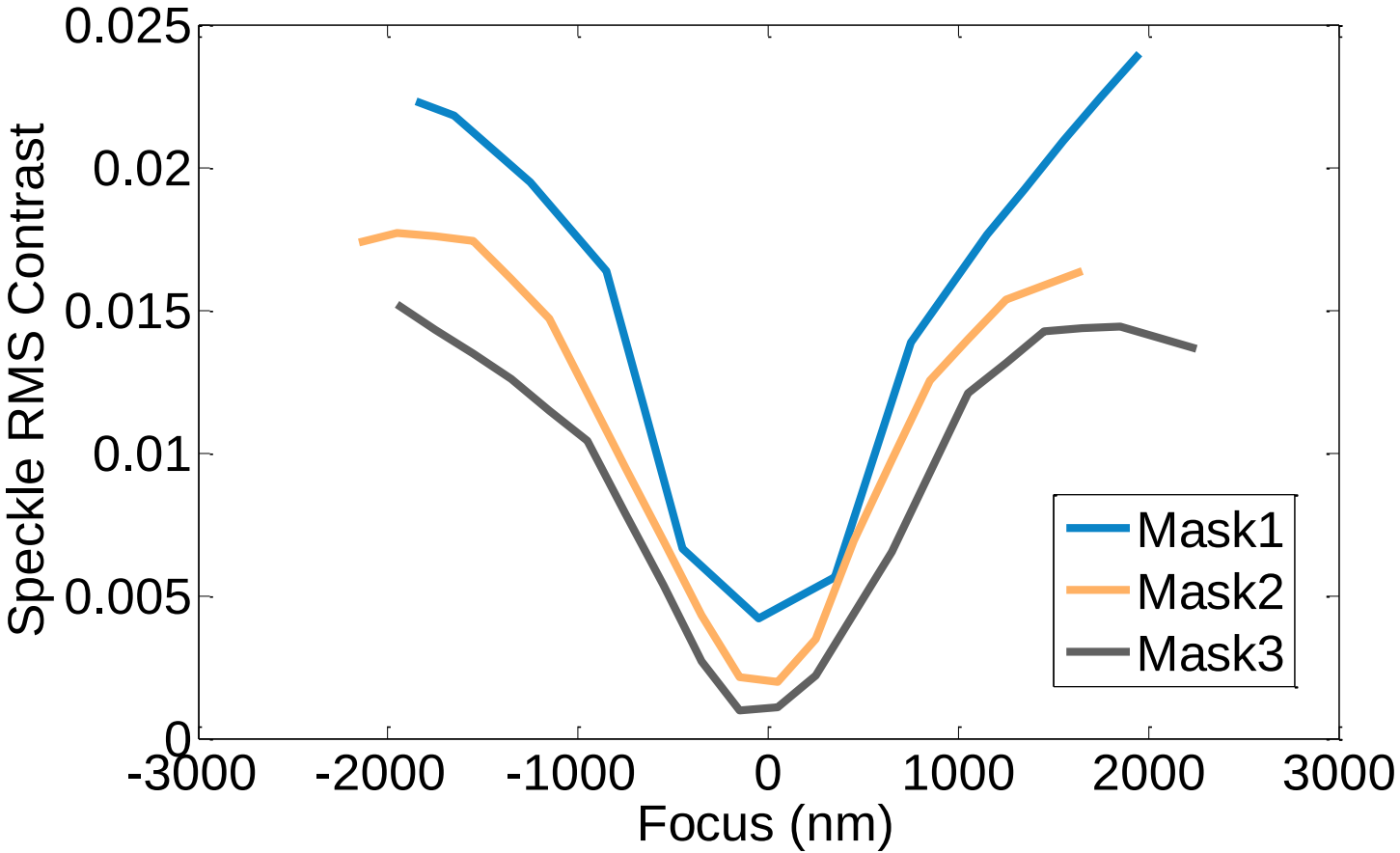
Mask 2


0.04
0.03
0.02
0.01
0
Speckle RMS Contrast
-3000
-2000
-1000
0
1000
2000
3000
Focus (nm)
0.1
0.3
0.5
0.7

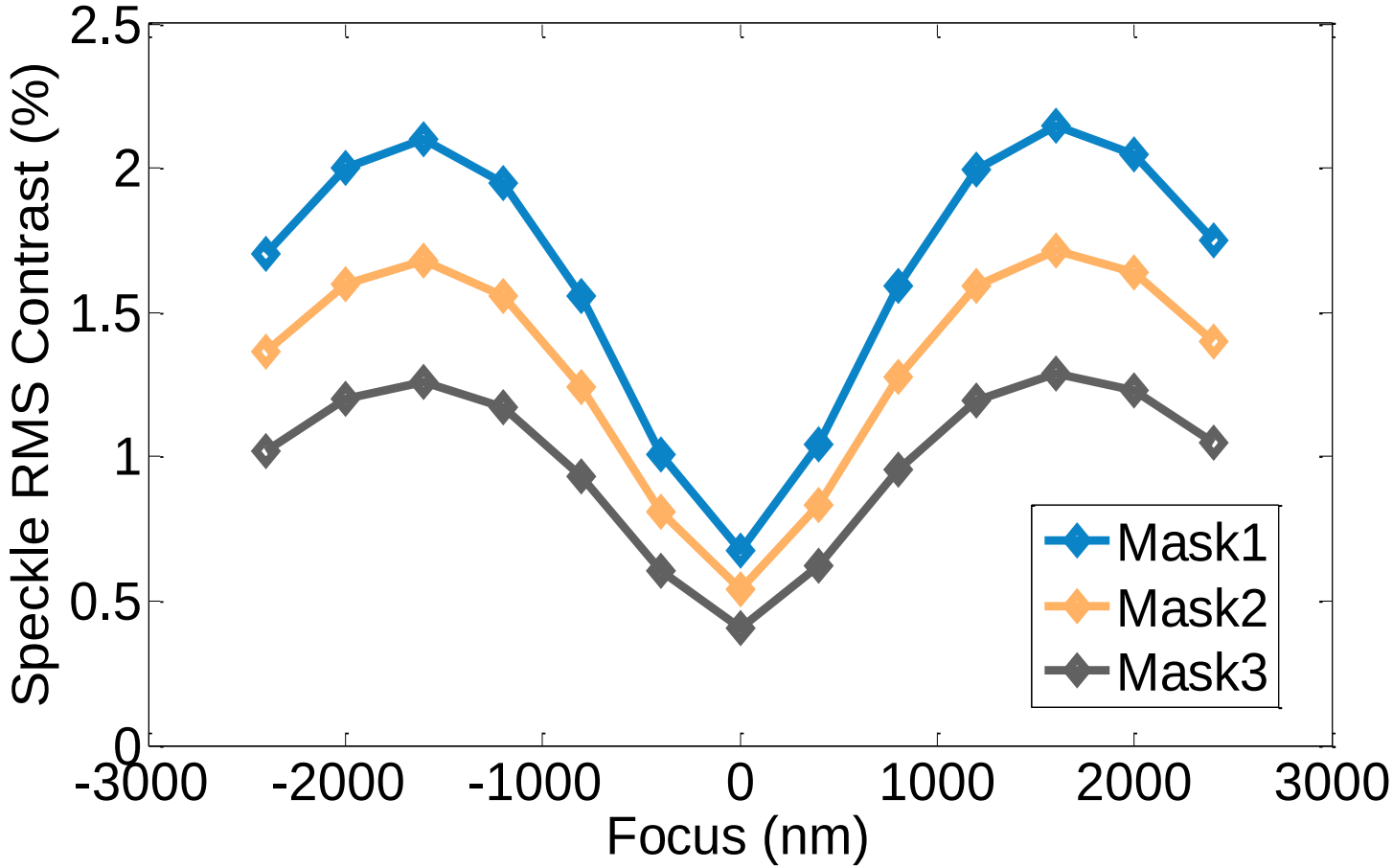
Mask 3


0.04
0.03
0.02
0.01
0
Speckle RMS Contrast
-3000
-2000
-1000
0
1000
2000
3000
Focus (nm)
0.1
0.3
0.5
0.7

$\sigma = 0.5$

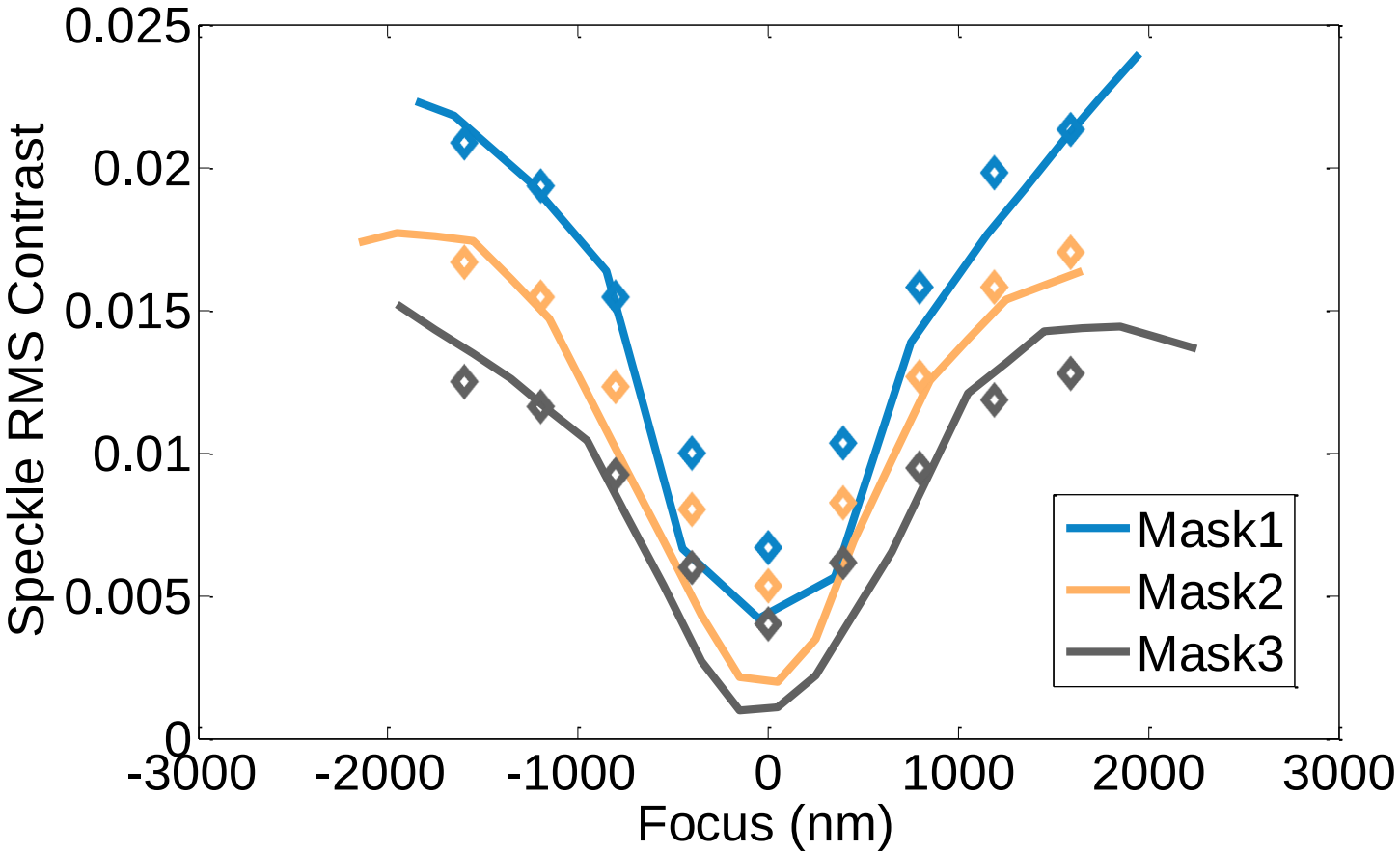

Speckle RMS Contrast
0.025
0.02
0.015
0.01
0.005
0
-3000
-2000
-1000
0
1000
2000
3000
Focus (nm)
Mask1
Mask2
Mask3

Modelled results assuming 1% amplitude



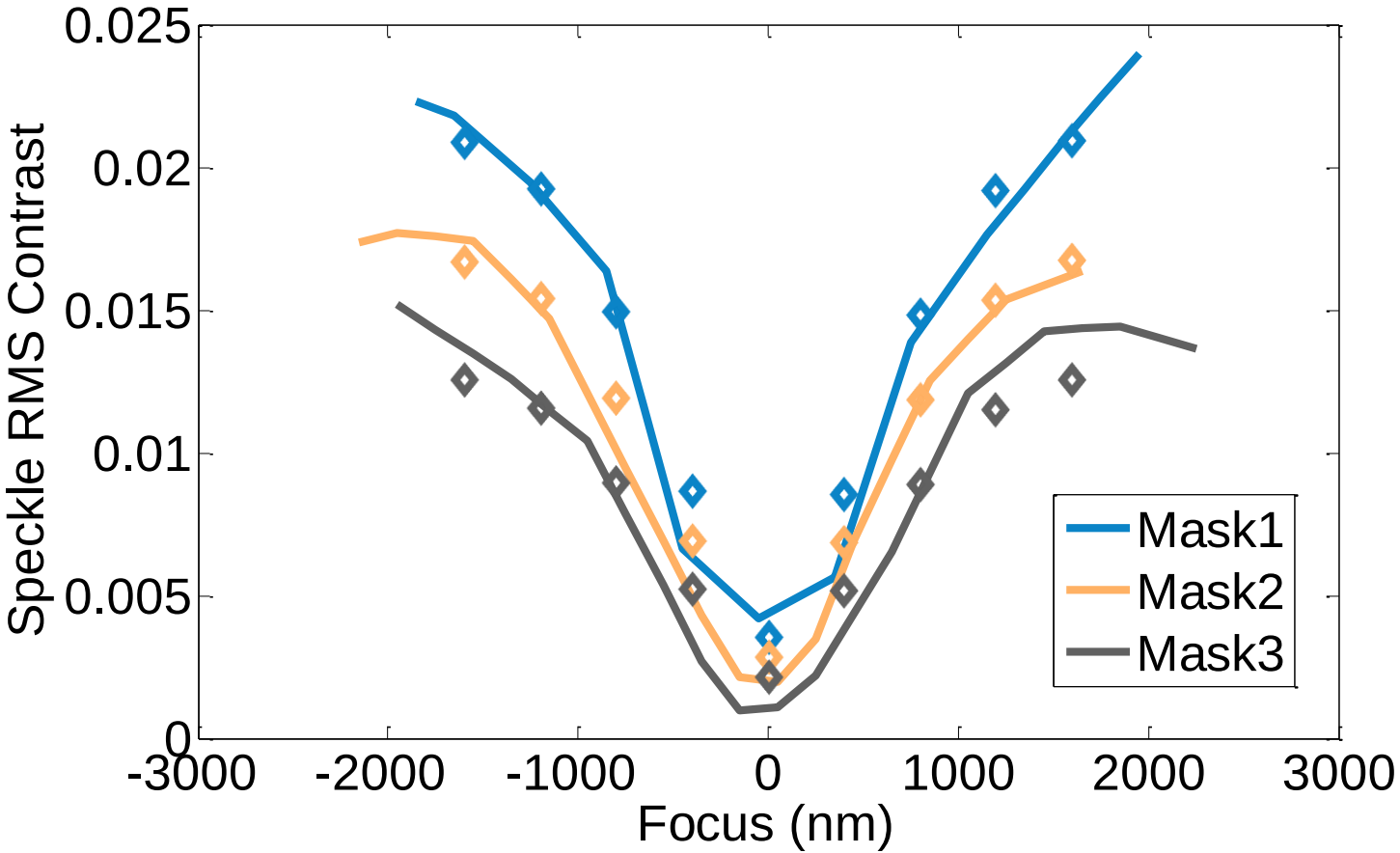
Partial coherence – 0.5

Exp vs expected with 1% amplitude



Partial coherence = 0.5

Exp vs expected with 0% amplitude



Partial coherence = 0.5

Comparison to modeling shows aerial image data consistent with <1% amplitude roughness for all 3 masks

Summary

- AFM does not accurately measure EUV roughness
- Scatterometry works only when assuming near pure phase roughness
- Comparison of modeling to aerial image measurements demonstrates amplitude effect to be less than 1% even for roughest mask considered

Thank You



